QUARTERLY REPORT

(for June - September 1997)

Contract No. NAS5-31363

OCEAN OBSERVATIONS WITH EOS/MODIS
Algorithm Development and Post Launch Studies

by

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I shall describe developments (if any) in each of the major task categories.

1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1997 there are seven objectives under this task. Task (i) below is considered to be the most critical. If the work planned under this task is successful, a module that enables the algorithm to distinguish between weakly- and strongly-absorbing aerosols will be included in the atmospheric correction algorithm.

(i) We will continue the study of the "spectral matching" algorithm with the goal of having an algorithm ready for implementation by the end of CY 1997. The initial realization of the algorithm will be to provide a flag that will signal the probable presence of absorbing aerosols, and indicate that the quality of the derived products cannot be assured. Later realizations will provide an atmospheric correction in the presence of absorbing aerosols.

(ii) We need to test the basic atmospheric correction algorithm with actual ocean color imagery. We will do this by looking at SeaWiFS imagery as they become available.

(iii) We must implement our strategy for adding the cirrus cloud correction into the existing atmospheric correction algorithm. Specific issues include (1) the phase function to be used for the cirrus clouds, (2) the details of making two passes through the correction algorithm, and (3) preparation of the required tables. These issues will be addressed during CY 1997 with the goal of having a complete implementation ready by the end of CY 1997.

(iv) The basic correction algorithm yields the product of the diffuse transmittance and the water-leaving reflectance. However, we have shown that the transmittance depends on the angular distribution of the reflectance only when the pigment concentration is very low and then only in the blue. We need to develop a method to include the effects of the subsurface BRDF for low-pigment waters in the blue.

(v) We will initiate a study to determine the efficacy of the present atmospheric correction algorithm on removal for the aerosol effect from the measurement of the fluorescence line height (MOD 20).

(vi) We will examine methods for efficiently including earth-curvature effects into the atmospheric correction algorithm. This will most likely be a modification of the look-up tables for the top-of-the-atmosphere contribution from Rayleigh scattering.

(vii) We will examine the necessity of implementing our out-of-band correction to MODIS.

b. Task Progress:

(i) We consider this task to be our most important atmospheric correction activity of 1997, and as such the major part of our effort on atmospheric correction will be focussed on it. During this quarter, we have further tested a "spectral matching algorithm" that, although very slow, is capable of distinguishing between weakly- and strongly-absorbing aerosols. The testing has focussed on three aspects:

(1) We have modified the algorithm so that it uses the same lookup tables (LUTs) as the basic MODIS atmospheric correction algorithm. This will make it possible to incorporate it into the present algorithm without the necessity of additional LUTs that contain redundant information.

(2) We are trying a new approach to the spectral matching, that utilizes power-law size distributions. This allows us to use straightforward interpolation to size distributions that are not part of the candidate set. We also interpolate on the real and imaginary parts of the complex refractive index. Thus, a complete spectrum of models can be generated from a relatively small candidate set. We then use standard optimization techniques to find the best fitting set of parameters. Initial tests are encouraging.

(3) We have also expended much effort toward increasing the speed of the present MODIS algorithm. Significant gains have been achieved by not computing everything at each pixel. Rather, the LUT values that are found for a given pixel are retained for 5-10 pixels. Although the is a small loss in accuracy, the increase in speed justifies it. This speed increase is an important, because the spectral matching algorithm is very slow.

(ii) We are arranging to get SeaWiFS imagery on a regular basis and are preparing to test the performance of the algorithm in its present state. To effect this we need to build a version of the MODIS algorithm that is specific to the SeaWiFS band set.

(iii) None. This task has been put on hold to free resources for examination of task (i).

(iv) No work was carried out on this task.

(v) No work was carried out on this task.

(vi) No work was carried out on this task.

(vii) The specifics on incorporating the out-of-band corrections in the MODIS algorithm have been worked out.

c. Anticipated Activities During the Next Quarter:

(i) We will test the "spectral matching" algorithm using synthetic data. Of particular interest will be finding ways to make it faster. We will commence testing the spectral matching algorithm with SeaWiFS data. Our goal will be to operate the spectral matching algorithm in such a manner as to provide a flag to indicate the presence of absorbing aerosols. Later implementations will include atmospheric correction in the presence of absorbing aerosols.

(ii) As more SeaWiFS imagery is acquired, we shall continue testing the algorithm.

(iii) None. The cirrus cloud issue in the presence of our "spectral matching" method needs to be explored. We will resolve the "spectral matching" questions first.

(iv) None.

(v) None.

(vi) None.

(vii) None, until we are provided with the final MODIS spectral response functions.

d. Publications:

H.R. Gordon, Atmospheric Correction of Ocean Color Imagery in the Earth Observing System Era, Jour. Geophys. Res., 102D, 17081--17106 (1997).

Y.J. Kaufman, D. Tanre, H.R. Gordon, T. Nakajima, J. Lenoble. R. Frouin, H. Grassl, B.M. Herman, M.D. King, and P.M. Teillet, Passive Remote Sensing of Tropospheric Aerosol and Atmospheric Correction for the Aerosol Effect, Jour. Geophys. Res., 102D 16815--16830 (1997).

2. Whitecap Correction Algorithm (with K.J. Voss)

As the basic objectives of this task have been realized, work is being suspended until the validation phase, except insofar as the radiometer will be operated at sea when sufficient number of personnel are available. Karl Moore, the post doctoral associated who was responsible for the operation of the instrument and the data analysis, has accepted a position at the Scripps Institution of Oceanography. In his absence our goal is to maintain experience in operating and maintaining the instrumentation in preparation for the validation phase of the contract.

a. Near-term Objectives:

Operate the radiometer at sea to maintain experience in preparation for the validation phase. Reduce data acquired during the Feb. 1997 cruise off Hawaii.

b. Task Progress:

An undergraduate student has been hired and is learning to reduce the data. At this point we have reduced the calibration data from the last cruise, and are progressing on the cruise data. In addition we are rewriting a manuscript on the previous data for submission to the EOS special issue.

c. Anticipated Activities During the Next Quarter:

We will be finishing the data reduction on the cruise data acquired during the February 1997 cruise. We will recalibrate the instrument in anticipation of a cruise in January 1998 with Dennis Clark. Finally we will finish rewriting the paper for the EOS special issue.

d. Publications: None.

3. In-water Radiance Distribution (with K.J.Voss)

The main objective in this task is to obtain upwelling radiance distribution data at sea for a variety of solar zenith angles to understand how the water-leaving radiance varies with viewing angle and sun angle.

a. Near-term Objectives: Acquire data with this instrument.

b. Task Progress:

Data was acquired during the July 1997 cruise with this instrument. We have reduced this data to radiometric quantities and are presently evaluating it. During this cruise we had an opportunity to take an extensive data set during one afternoon, in which data was acquired with sun angles varying from approximately 40 degrees to 85 degrees. This will give us a good data set to evaluate the effect of sun angle on the upwelling radiance distribution, i.e., bidirectional effects, near the MOBY site.

c. Anticipated Activities During the Next Quarter:

We will continue to evaluate and work with the data acquired during the July cruise. In addition we will be calibrating the instrument in anticipation of a cruise in January, 1998 with Dennis Clark.

d. Publications: None.

4. Residual Instrument Polarization.

The basic question is, if the MODIS responds to the state of polarization state of the incident radiance, given the polarization-sensitivity characteristics of the sensor, how much will this degrade the performance of the algorithm for atmospheric correction? We have developed a formalism which provides the framework for removal of instrumental polarization-sensitivity effects, and an algorithm for removing much of the error induced by the polarization sensitivity.

a. Near-term Objectives: None.

b. Task Progress: None

c. Anticipated Activities During the Next Quarter:

Incorporate SBRS/MCST polarization-characterization data into our module for correcting for the MODIS residual instrument polarization.

d. Publications:

H.R. Gordon, T. Du, and T. Zhang, Atmospheric Correction of Ocean Color Sensors: Analysis of the Effects of Residual Instrument Polarization Sensitivity, Applied Optics, 36, 6938--6948 (1997).

5. Pre and Post-launch Atmospheric Correction Validation and Vicarious Calibration/Initialization (with K.J. Voss)

a. Task Objectives:

The objectives of this task are four-fold:

(i) First, we need to study aerosol optical properties over the oceans to assess the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this requires obtaining long-term time series of the aerosol optical properties in typical maritime environments. This will be achieved using a CIMEL sun/sky radiometer that can be operated in a remote environment and send data back to the laboratory via a satellite link. These are similar to the radiometers used by in the AERONET Network.

(ii) Second, we must be able to measure the aerosol optical properties from a ship during the initialization/calibration/validation cruises. The CIMEL-type instrumentation cannot be used (due to the motion of the ship) for this purpose. The required instrumentation consists of an all-sky camera (which can measure the entire sky radiance, with the exception of the solar aureole region) from a moving ship, an aureole camera (specifically designed for ship use) and a hand-held sun photometer. Our objective for this calendar year is to make measurements at sea with this instrumentation, both to collect a varied data set and to test the instrumentation and data reduction procedures. We are working on the data reduction procedures to allow measurements to be reduced in almost real time (each night) so that almucantar and principal plane measurements can be obtained quickly.

In the case of strongly-absorbing aerosols, we have shown that knowledge of the aerosol vertical structure is critical. Thus, we need to be able to measure the vertical distribution of aerosols during validation exercises as well as building a climatology of the vertical distribution of absorbing aerosols. This will be accomplished with ship-borne LIDAR. We have procured a LIDAR system and modified it for ship operations.

(iii) The third objective is to determine how accurately the radiance at the top of the atmosphere can be determined based on measurements of sky radiance and aerosol optical thickness at the sea surface. This requires a critical examination of the effect of radiative transfer on ``vicarious'' calibration exercises.

(iv) The forth objective is to utilize data from other sensors that have achieved orbit (OCTS, POLDER, MSX SeaWiFS) to validate and fine-tune the correction algorithm.

b. Task Progress:

(i) We have been operating the CIMEL instrument in the Dry Tortugas continuously during this quarter.

(ii) We acquired more surface sky radiance data, and aureole measurements with the instruments during a July cruise in Hawaii. We have reduced this data to radiometric units, and are currently validating this data set.

We deployed the LIDAR during the ACE-II experiment in Tenerife to look at the height distribution and backscattering characteristics of Saharan Dust. We acquired an extensive test data set with the instrument, and some dust events (this year did not have the typical weather patterns, and less dust than expected). We are currently working with this data set, however the MPL LIDAR developed an asymmetric output pattern, due to a laser problem, and has been sent back to the manufacturer for repair. We anticipate receiving the LIDAR, after the repair, in time for the January cruise.

(iii) The theoretical aspects of this work have been completed. The next phase is to use surface measurements to predict top-of-atmosphere radiance.

(iv) We are preparing a duplicate version of the MODIS algorithm code to use the SeaWiFS spectral bands. This will be used to test the MODIS code with SeaWiFS data.

c. Anticipated Activities During the Next Quarter:

(i) Early in the quarter the CIMEL instrument in the Dry Tortugas will be removed and sent to NASA for recalibration. After that, the instrument will be reinstalled in the Dry Tortugas. We are also working with others to allow us some sort of automated access to the data in the AERONET network. This will allow us to work with the data in a simpler fashion.

(ii) We will continue to work with the July data set. In addition we must calibrate the instruments in anticipation of the January cruise. We will also be working with the LIDAR data, acquired during ACE-II, developing data reduction algorithms and data calibration techniques.

(iii) We will use data acquired during the July cruise to test the vicarious calibration algorithms.

(iv) We anticipate processing SeaWiFS imagery with MODIS code.

d. Publications:

D.K. Clark, H.R. Gordon, K.J. Voss, Y. Ge, W. Broenkow, and C. Trees, Validation of Atmospheric Correction over the Oceans, Jour. Geophys. Res., 102D 17209--17217 (1997).

K.J. Voss and Y. Liu, Polarized radiance distribution measurements of skylight: Part 1, system description and characterization, Applied Optics, 36, 6083--6094 (1997).

6. Detached Coccolith Algorithm and Post Launch Studies.

a. Near-term Objectives:

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, E. huxleyi is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies focused on laboratory cultures to understand factors affecting the calcite-specific backscattering coefficient. A thorough understanding of the relationship between calcite abundance and light scattering, in situ, will provide the basis for a generic suspended calcite algorithm. As with algorithms for chlorophyll, and primary productivity, the natural variance between growth related parameters and optical properties needs to be understood before the accuracy of the algorithm can be determined. To this end, the objectives of our coccolith studies during this last quarter have been to a) complete all analyses of our flow cytometry experiments (examining the calcite-specific backscattering coefficient of calcite particles sampled in the field), b) prepare the results for publication, c) work-up samples and data from our pre-launch cruise in the Gulf of Maine last June, and d) prepare for our upcoming pre-launch cruise in the Gulf of Maine in November.

b. Task Progress:

Overview of MODIS work

For perspective on the directions of our work, we provide a brief overview of our previous activities. During 1995, we focussed on the above objectives using chemostat cultures (in which algal growth rate was precisely controlled). During the latter half of 1995, our work focused on shipboard measurements of suspended calcite and estimates of optical backscattering as validation of the laboratory measurements. We participated on two month-long cruises to the Arabian Sea, measuring coccolithophore abundance, production, and optical properties. During 1996, we focused again on an examination of coccolith optics, during three Gulf of Maine cruises, one in March, one in June, and one in November. During 1997, we completed yet another cruise in the Gulf of Maine, in which we provided some of the only sea-truth numbers for the now defunct Japanese OCTS instrument, as well as collecting pre-launch data for MODIS.

Work performed this quarter

1) Processing of the suspended calcite samples from the June '97 cruise. We are still processing the CHN samples, which will be important for understanding the backscattering arising from suspended organic matter.

2) Final analysis and write-up of our flow cytometer experiments. This manuscript is now complete. Next week, it will be submitted for the MODIS special issue to appear in J. Geophys. Res. next year.

3) Continued microscope cell/ coccolith counts for samples from the Gulf of Maine. We are processing count data from '96, and working on enumeration of '97 samples.

4) A paper on coccolith optics with Ken Voss and Katherine Kilpatrick, has been reviewed, revised, and sent back to Limnology and Oceanography. It should appear in print in 6-9 months. The paper deals with a laboratory comparison of volume scattering instruments, using the coccolithophore, Emiliania huxleyi, and how to model the optical properties.

c. Anticipated Activities During the Next Quarter

1) Continued processing of the large amount of underway data on calcite-dependent light scattering that has been collected in the Gulf of Maine and Arabian Sea. We are beginning a manuscript on the Arabian Sea backscattering data.

2) Continued microscope cell/ coccolith counts for water samples from the Gulf of Maine.

3) We will go to sea in November on another Gulf of Maine cruise. The cruise will load on 3 November, and finish by 22 November, 1997.

d. Publications

One manuscript is in press at this time. The paper deals with a new way to estimate gradients in biomass and primary production from space. The citation is:

Balch, W. M. and B. Bowler. Sea surface temperature gradients, baroclinicity, and vegetation gradients in the sea. In press J. Plank. Res.

The following manuscript has been accepted and is in final revision before publication: Voss, K., W. M. Balch, and K. A. Kilpatrick. Scattering and attenuation properties of Emiliania huxleyi cells and their detached coccoliths. In revision for Limnol. Oceanogr.

OTHER DEVELOPMENTS

The PI participated in the SIMBIOS meeting in Maryland in August.